Agent-Based Modeling of Food Accessibility: Insights for Policy and Decision-Making

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1 INTRODUCTION

The UN Sustainable Development Goal (SDG) 2, "Zero Hunger," aims to end hunger, achieve food security, improve nutrition, and promote sustainable agriculture by 2030 (SDG, n.d.). SDG2 emphasizes equitable food access and security for all, especially vulnerable populations. However, food insecurity is a pressing challenge that impacts millions, even within developed countries like the United States (Fee, 2024). Vulnerable communities often lack reliable access to nutritious food, a situation exacerbated by disparities in distribution infrastructure. Despite efforts from numerous NGOs and governmental bodies, food insecurity persists, underscoring the urgent need for effective, data-driven policy tools. This study presents the Food Access Strategy Simulator (FASS), an agent-based model designed to empower policymakers to evaluate the community-level impacts of strategic food distribution placements (*i.e.,* supermarkets, food pantries, farmers markets). FASS models individual and community behaviors, assessing how policy decisions affect food security outcomes in vulnerable areas. By simulating interactions and resource distribution across diverse demographics, FASS provides data-driven insights, promoting equity in food access and supporting informed decision-making for both government and nonprofit stakeholders.

2 METHODOLOGY

The Food Access Strategy Simulator (FASS) leverages an Agent-Based Modeling (ABM) approach to simulate complex dynamics in food distribution and access. Agent-Based Modeling (ABM) is a simulation modeling technique in which individual entities, or agents, are assigned distinct behaviors and interactions within an environment to simulate complex systems at the micro level (Bonabeau, 2002, Macal & North, 2005). In the FASS the ABM's decentralized approach allows each agent—representing community households and distribution points—to operate based on specific rules and interactions, producing emergent outcomes that reflect real-world complexity. Hence, an ABM is particularly suited to capture diverse consumer behavior and access needs, enabling assessments of distribution scenarios and their effects on food security for vulnerable communities (Railsback & Grimm, 2019).

2.1 ABM MODEL DEVELOPMENT

The agent-based model in FASS advances the framework established by previous work, which relied on a proprietary simulation package that limited adaptability. In contrast, FASS is built as a fully independent model in Python 3.11.4, providing flexibility to integrate diverse agent behaviors and incorporate additional environmental variables. This independent implementation creates a robust, adaptable simulation environment, enhancing FASS's utility for policymakers and researchers evaluating diverse food access scenarios.FASS further incorporates detailed agent attributes to represent food accessibility more accurately. Each household agent is assigned specific characteristics—including income, household size, number of children, employment status, and transportation access—that collectively shape their food access decisions. This granularity captures unique household circumstances often obscured at higher aggregation levels, resulting in a more precise model for food access analysis.

2.2 FOOD ACCESS

For this study we calculate food access using a Monthly Food Access Index (MFAI), which reflects the agents' food access over multiple grocery trips i within a month. This index assigns scores based on store type T, transportation mode V, and agent characteristics A, income level B and vehicles available ν. For each simulated trip, agents (*i.e.*, households) probabilistically select either a convenience store or a supermarket, with the probability of choosing a store S increasing with the agents characteristics, and vehicle availability. Then equation representing this probabilistic choice $P(S)$ of an agent can be written as:

$$P(S) = \left(\frac{\mathrm{A}}{b} \times w_\beta \right) + (\nu \times w_\nu) + c \tag{1}$$

Where b is a constant that represents the maximum income of the population, w_β is the weight of the budget available in the agents decision, w_ν is the weight of the vehicle in the agents decision, and c is the constant that ensures that every agent has access to a food source. Using Equation 1 we can then calculate the MFAI by distributing the probability of selecting a distribution point S over the number of trips $i = \{1, 2, 3...n\}$ an agent can make. Hence, MFAI can be written as follows.

$$\mathrm{MFAI} = \frac{1}{n} \sum_{i=1}^{n} T_i \times P(S) \tag{2}$$

Equation 2 averages the scores trips to stores, with each trip weighted by the likelihood of selecting a supermarket based on characteristics and vehicle access, providing an measure of access to food options. Note that agents have a higher score when visiting a store with a larger food selection, especially if they have vehicle access, reflecting greater access to nutitionous food options.

3 PRELIMINARY EXPERIMENTS AND RESULTS

The Food Access Strategy Simulator (FASS) was initially applied to Franklin County, Columbus, Ohio, focusing on census tracts to provide detailed, localized insights into food access. Franklin County was chosen for its socioeconomic diversity, encompassing both high-income areas and a significant number of households below the poverty line, making it an ideal site to analyze food insecurity dynamics. Census tracts, each covering between 1,200 to 8,000 individuals, were selected due to their granularity in socioeconomic data, obtained from the American Community Survey (ACS) (Bureau, 2024). To accurately represent the demographic and socioeconomic diversity, a multi-step process was used to assign agent attributes. Income distribution for each census tract was calculated by income buckets as defined by ACS, allowing agents to be randomly assigned an income level within these proportions. For example, if 20% of a tract's population falls within the \$25,000 to \$30,000 income range, 20% of agents receive an income within this range. Household sizes were also randomly assigned from one to four members based on census data, while vehicle availability and the number of workers per household were determined using ACS variables such as "Household Size by Vehicles Available" and "Number of Workers by Vehicles". This approach reflects realistic distributions and provides detail in understanding access disparities. Additionally, food store data was obtained via the Open Street Maps API, filtered by relevant keywords, including "supermarket", "convenience store", "butcher", and "grocery". Each store was then mapped to a specific geographic location within Franklin County, categorized by type to facilitate analysis of food variability and access. Furthermore the classification of food stores was divided into two primary categories: supermarkets, which generally offer a wider variety of healthy food options, and convenience stores, which often lack diverse food selections. This classification enables FASS to differentiate access levels based on store type, aligning with literature on the nutritional disparities between store categories.

3.1 EXPERIMENTAL RESULTS

Running the agent-based model (ABM) on the Columbus dataset, which includes three convenience stores and one supermarket, produced an average MFAI score of 84.22 across households (see Figure 1). This score was calculated based on the probability-weighted choice between supermarkets and convenience stores, influenced by household attributes such as income and vehicle ownership using Equations 2 an 1. The parameters were as follows maximum income of the population $b = 200,000$, the weight of the budge $w_\beta = 10$, weight of the vehicle $w_\nu = 5$, and the access constant $c = 60$. The experiment accounted for a total of seven trips ($i = 1, 2, 3, 4, 5, 6, 7$) In this experiment the MFAI reflects the likelihood of households opting for supermarkets over convenience stores.

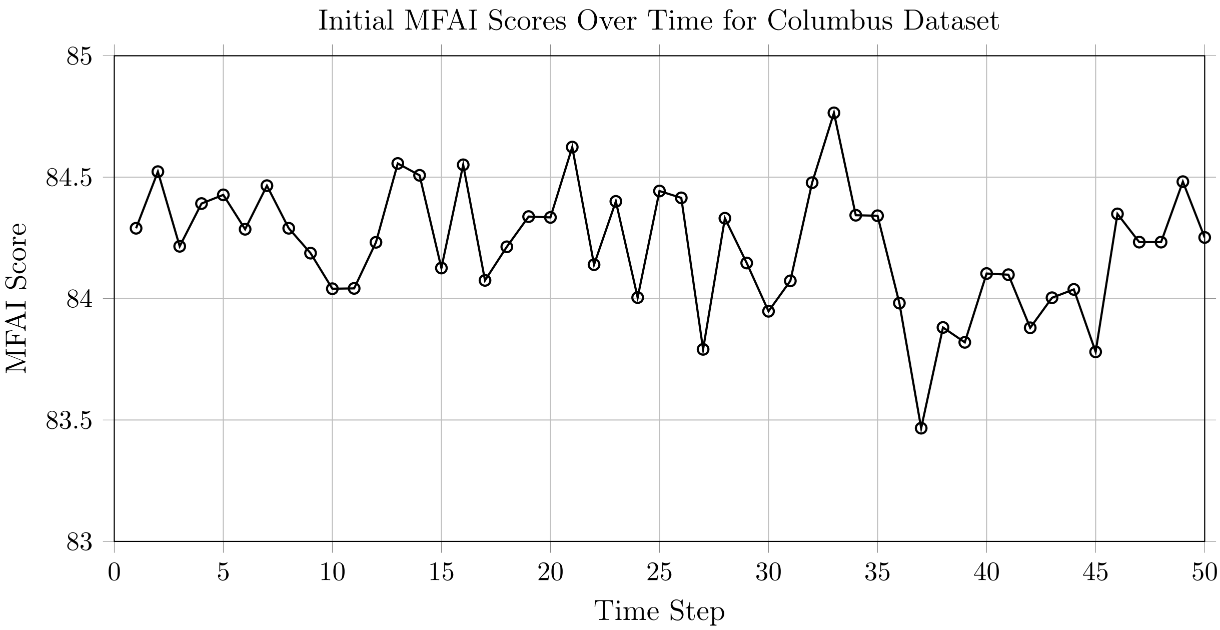

Figure 1 – *Graph of initial MFAI scores over time for Columbus dataset*

The MFAI score shows fluctuations across time steps, driven by the probability of each agent selecting a supermarket or convenience store during simulated trips.

3.1.1 IMPACT OF STORE TYPE REMOVAL

A sensitivity analysis was conducted by altering the availability of store types to assess the influence on the MFAI score. Removing the sole supermarket in the dataset caused a substantial drop in the MFAI to 49.26, indicating a significant reduction in food access quality when households rely exclusively on convenience stores. This change underscores the critical role that supermarkets play in maintaining higher levels of food access (See Figures 2 and 3). As shown in the time-series data, MFAI scores stabilize at a lower level when households deterministically select convenience stores due to the absence of a supermarket option. This highlights the value of supermarkets in reducing food deserts and improving overall food accessibility within vulnerable communities.

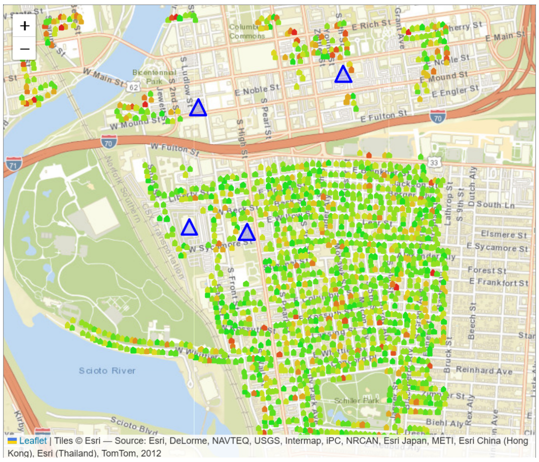

Figure 2 – *Four Stores*

average MFAI score of 84.22

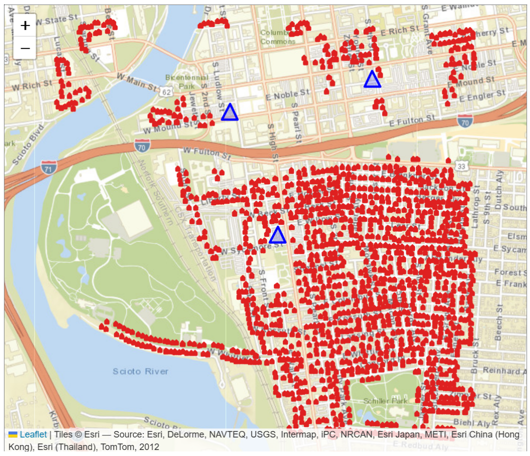

Figure 3 – *Three Stores*

average MFAI score of 49.26

4 FUTURE WORK

This is ongoing work. While the current version provides a framework for assessing food accessibility, limitations exist. Currently, the MFAI does not account for the distance between households and stores, an important factor in real-world food accessibility. Incorporating distance will improve the model's accuracy and reflect the travel burdens faced by households in accessing food. Future iterations will also integrate additional factors, such as weather conditions and transportation infrastructure, to capture dynamic influences on food access. Long-term plans for FASS include expanding the model to more geographic regions and incorporating more complex household dynamics. By addressing these areas, FASS will serve as an adaptable tool for guiding effective policies to reduce food insecurity. Additional results obtained by the time of the conference will be included in the presentation.

References

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